Solutions

Marking: **M1** a correct method, **A1** the correct answer, **B1** an independent mark.

Each answer shows the steps, then the **result**.

2.1

$n_s = \dfrac{120 \times 60}{4} = \mathbf{1800\ rpm}$; $s = \dfrac{54}{1800} = \mathbf{0.03}$; $f_r = 0.03 \times 60 = \mathbf{1.8\ Hz}$

2.2

rotor copper loss $= 0.05 \times 15 = \mathbf{0.75\ kW}$; mechanical $= \mathbf{14.25\ kW}$; $T = \dfrac{15\,000}{157.1} = \mathbf{95.5\ N\ m}$

2.3

$\dfrac{0.3}{0.03} = 10\ \Omega = 0.3 + \mathbf{9.7}\ \Omega$; copper loss $= 3 \times 20^2 \times 0.3 = \mathbf{360\ W}$; mechanical $= 3 \times 20^2 \times 9.7 = \mathbf{11.6\ kW}$; check $\dfrac{360}{12\,000} = 0.03 = s$

2.4

$P_{ag} = 12 - 0.6 = \mathbf{11.4\ kW}$; mechanical $= 0.96 \times 11.4 = 10.94$ kW, shaft $= 10.94 - 0.25 = \mathbf{10.69\ kW}$; $\eta = \dfrac{10.69}{12} = \mathbf{89.1}\%$

3.1

$V = 231$ V per phase, $\omega_s = 157.1$ rad/s; $R_2'/s = \mathbf{10.0}\ \Omega$

$|Z| = \sqrt{10.4^2 + 2.0^2} = 10.59\ \Omega$, $I = \dfrac{231}{10.59} = \mathbf{21.8\ A}$

$T = \dfrac{3 \times 21.8^2 \times 10}{157.1} = \mathbf{90.8\ N\ m}$

$s_{max} = \dfrac{0.35}{\sqrt{0.4^2 + 2.0^2}} = \mathbf{0.172}$

at s_{max}: $R_2'/s = 2.04\ \Omega$, $I = 73.2$ A, $T_{max} = \dfrac{3 \times 73.2^2 \times 2.04}{157.1} = \mathbf{209\ N\ m}$

3.2

for $s_{max} = 1$: $R_2' + R_{ext} = \sqrt{0.4^2 + 2.0^2} = 2.04\ \Omega$, so $R_{ext} = \mathbf{1.69}\ \Omega$

starting torque $= T_{max} = \mathbf{209\ N\ m}$, almost three times 78 N m

rotor loss $= sP_{ag}$: **20**% of the air-gap power, against 3.5% without it

cut the resistance out in steps as the motor speeds up, so it runs at the low slip

3.3

(a) 78 N m is enough to break away; 108 A breaks the 60 A limit, so it fails

(b) $\dfrac{108}{3} = 36$ A, which passes; $\dfrac{78}{3} = \mathbf{26\ N\ m} < 40$ N m: the compressor does not start

(c) $0.7^2 = 0.49$: $0.49 \times 108 = \mathbf{53\ A}$, which passes; $0.49 \times 78 = \mathbf{38\ N\ m} < 40$: just fails

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(d) either unload the compressor at start (open its unloader valve) so it needs far less torque, then star-delta works; or use a variable-frequency drive, which gives full torque at about rated current; a start method must meet the current limit and the load torque at once